In-Situ Recycling of Asphalt Concrete as Base Material in California

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Abstract. The California Department of Transportation conducted a pilot project for evaluating a pulverization process for asphalt concrete to use it as a base material. The technique is relatively new to California and in concept, presents several advantages over the conventional overlay strategy. The process was evaluated in terms of constructability and pavement performance. The process provided Caltrans engineers with lower initial costs than overlay with digouts in the wheelpath. Field and laboratory testing were conducted at the University of California Pavement Research Center to evaluate the new materials using falling weight deflectometer deflections, dynamic cone penetrometer, and triaxial testing. The results of the investigation indicate that the pulverized base material is expected to perform better than the conventional base materials used in the study. The results also show greatly improved properties of granular base materials, including this recycled material when the relative density is increased from 95 to 100 percent using Caltrans standard compaction.

INTRODUCTION

A pilot project for in-place recycling of asphalt concrete and placing it as a granular base material was conducted by the California Department of Transportation (Caltrans) District 2 to evaluate a construction specification using this rehabilitation strategy. The technique requires that the asphalt concrete layer is pulverized and mixed with a portion of the existing underlying base material to create a new base layer. The technique is relatively new to California and presents several significant advantages over current rehabilitation techniques. The conventional rehabilitation technique in California requires an asphalt concrete overlay over the prepared existing pavement. For severe distress flexible pavements, digouts are used to preserve the pavement structural condition by removing the localized surface distresses (fatigue alligator cracking, potholes, etc.) prior to construction of the overlay. Cold in-place recycling with asphalt emulsions has also been used by Caltrans in the past. This project is the first in California where thick layers of asphalt concrete are pulverized to a specified gradation and recompacted in-place as a high quality granular base layer.

Caltrans engineers concluded based on economic comparisons, constructability, and laboratory and field testing, that this rehabilitation process is a feasible alternative to the conventional overlay strategy (1). Material evaluations conducted at the University of California, Pavement Research Center using triaxial laboratory testing and field testing (falling weight deflectometer and dynamic cone penetrometer) indicated that the pulverization process provided a superior product to that existing in situ prior to the rehabilitation (2). This paper presents an overview of the rehabilitation process with comparisons of strategies based on pavement condition, costs, construction time, traffic delay, etc. The laboratory and field testing and estimation of pavement life indicate the superior performance of the pulverized asphalt concrete.

PROJECT DESCRIPTION AND PAVEMENT CONDITION

The rehabilitation project was located on California State Highway 395 between post mile 13 and 10, approximately 10 miles south of Alturas, California. The existing structural section prior to construction consisted of 82 to 183 mm (3.2 to 7.2 in.) of asphalt concrete over 145 to 225 mm (5.7 to 8.9 in.) of aggregate base. The condition survey indicated that the pavement was in poor condition, primarily with severe alligator cracking and occasional pot-holing. The estimated traffic volume for a 10-year pavement life was 1.0 million ESALs. The average daily traffic is 1,550. (1)

REHABILITATION STRATEGIES AND SELECTION

The rehabilitation alternatives considered for the project included an asphalt concrete overlays with 20 percent digouts, an asphalt concrete overlay with 40 percent digouts, cold in-place recycling with asphalt emulsions, and the asphalt concrete pulverization process.

Asphalt Concrete Overlays and Digouts

Overlay Thickness Determination

Asphalt concrete overlays are obtained following Caltrans Test Method (CTM) 356 (3). In the method, the surface pavement deflection resulting from the application of an 80-kN single axle load is measured and compared to previously determined allowable limits for a similar pavement structure and traffic volume. An overlay thickness is determined sufficient to reduce the deflection to a level at which the surface is unlikely to fail due to fatigue. The most recent deflection study indicated an asphalt concrete overlay thickness of 165 mm (6.5 in.) for structural adequacy.

Because of the existing condition prior to rehabilitation, the mode of failure of the proposed overlay was most likely reflection cracking rather than fatigue failure, as stated in the overlay design process. Caltrans asphalt concrete overlays obtained following Caltrans test method 356 typically yield an average pavement life of 9 years when designed for 10 years (4).

Digout Preparation

Before placing the asphalt concrete overlays, the existing pavement is prepared by conducting digouts. Digouts require saw cutting, removal and placement of a new asphalt concrete over potholes and severely alligator cracked areas. Digouts are usually conducted when the surface distress is approximately 20 percent of the pavement surface

(20 percent digout) or greater. Extensive digouts may be necessary if a significant amount of surface distress is present on the pavement. The cold joint at the digout edges can create a longitudinal crack that can turn into a potential reflective crack on the new asphalt concrete overlay.

Cold In-Place Recycling with Asphalt Emulsion

This strategy was not evaluated because the traffic level makes it difficult for Caltrans to keep speeds down, and trucks off of the route while the emulsion cures. There were no alternate routes around the construction site. In general, Caltrans engineers are exploring alternatives to in-place recycling with emulsions because even the lowest volume state highways have fairly substantial traffic.

Asphalt Concrete Pulverization into Aggregate Base

Concept

The pulverization rehabilitation process requires that the asphalt concrete be pulverized and mixed with the existing base material and compacted to create a new base layer. The pulverized material should meet the Class 2 aggregate base requirements according to the proposed specification, graded to the established lines and grades, and compacted to 95 percent maximum density according to Caltrans test method 216 (5). During construction, approximately 200 mm (8 in.) of existing asphalt concrete and aggregate base were pulverized. An asphaltic emulsion curing seal was placed as a tack coat for the new 150-mm (6 in.) asphalt concrete layer.
Cementation of the granular base layer is considered undesirable because it will eventually crack and present recurring reflection cracking problems, the elimination of which is a key objective of the pulverization process.
This strategy was very attractive for Caltrans engineers because it eliminates the severely cracked asphalt concrete pavement and the use of digouts that typically cause reflective cracking on the new asphalt concrete layer. In terms of constructability, the pulverization process simplified the paving operations thereby increasing the production rate. For instance, when a crown correction was needed, this strategy eliminates the need for a leveling course before paving the mainline. In addition, if road widening is required, this strategy eliminates the widening operation as a separate operation.
The increase in production rate can be reflected in a reduction in traffic delays that could otherwise cause inconvenience to the road users and safety concerns. In addition, because the process makes use of in-situ material, several items such as roadway excavation, imported material for shoulder backing, aggregate base material, crack sealing, asphalt concrete replacement of the digouts, and reinforcing fabrics, were eliminated from the contract document.

Construction

For the grinding process, the contractor used a CMI RS-650 rubber tired grinder. The resulting product was a material with some oversize particles. A CAT 815 B compactor was then used to break-up some of the oversize material and obtain initial compaction. A secondary compaction was accomplished with an Ingersoll-Rand PT 125 pneumatic roller before grading. Then, the layer was graded with a Bomag BW 213 D-2 and final compaction was accomplished with an Ingersoll Rand DD 110 HF.
Watering the material was very important in order to obtain the specified field density (95 % maximum density according to California Test Method 216). Poor results were obtained when adding water at the grinder because water was concentrating in certain areas resulting in an unstable condition. The best results were obtained when the contractor ground out the existing roadway then watered the material and then ran the grinder over the same material a second time breaking up the oversize particles and mixing water evenly through the material before compaction.
The main problem found during construction was the oversize material, which caused problems in the grading and compaction processes. Caltrans engineers suggested that the best method to overcome the problem of the oversize material is to use a crusher right after the material is ground out.

Strategy Selection

The key issue for Caltrans design and maintenance engineers is the selection of the most cost-effective rehabilitation strategy for each project based on:

- The cost per lane-km of each strategy, which incorporates the unit cost of the material and the thickness used, and
- The performance of each strategy in terms of truck load repetitions to reach a defined failure conditions, translated to years.

INITIAL COST

Table 1 shows the comparison of initial costs of three strategies considered for the pilot project.(1) The comparison indicates that the pulverization process has a lower initial cost than the conventional rehabilitation strategy. The cost comparison shown in Table 1 does not include traffic delays or maintenance activities.

PAVEMENT PERFORMANCE

Based on the Caltrans pavement management system (4), the conventional overlay strategy yields a pavement life of 5 to 10 years. No estimates of pavement life could be determined from the current Caltrans design procedure for the pulverization strategy since no calibrated gravel factors (empirical material coefficients) are specified for this type of materials. The current Caltrans design procedure is a semi-empirical design method based on the R-value of the paving materials and corresponding gravel factors.

Due to the shortcoming of the current design procedure, field and laboratory testing using state of the art pavement analysis techniques were used to evaluate the performance of the pulverization process. The field testing included falling weight deflectometer (FWD) and dynamic cone penetrometer (DCP) testing before and after the pulverization process. The laboratory testing was conducted to characterize the pulverized asphalt concrete material under standard and triaxial laboratory tests, and to compare the laboratory performance of the pulverized material with typical California aggregate base Class 2 materials.

Field Testing Program

Two series of field tests were conducted along the project. The first series of tests were conducted on the existing pavement on June 1 2001, and the second series of test were conducted on the rehabilitated road using the pulverization process on September 27, 2001. The field tests included 1) coring, 2) DCP testing, and 3) FWD testing. These tests were conducted along the south bound (SB) and north bound (NB) lanes. For purposes of analysis, the starting station is 0.0 m. at post mile 13 and the ending station is 4800 m. at post mile 10. Portion of the project between stations 3200 m. and 4800 m. was not subjected to the rehabilitation process.

Coring

Coring of the asphalt concrete (AC) layer was conducted to obtain asphalt concrete thickness profiles along the pavement section. Asphalt concrete thicknesses were used during the mechanistic pavement analysis. Coring was conducted before and after the pulverization process by the Caltrans District 2 crew along the south and north bound lanes. After the pulverization process, coring was conducted on the shoulder, approximately 0.5-m from the shoulder paint mark. Asphalt concrete thicknesses were variable before and after the pulverization process. Asphalt concrete thicknesses ranged from 125 to 250 mm.

Dynamic Cone Penetrometer (DCP)

After the asphalt concrete cores were removed from the core holes, DCP testing was conducted for field measurements of thickness and strength of unbound layers. Changes in the penetration rate (DN = slope of the penetration-blow count relationship in mm/blow count) were used to determine thickness of unbound layers. The penetration rate at a given layer was also used to define its strength. In general, lower penetration rates are indicative of stronger materials.

Estimated base thicknesses showed significant variability before the pulverization process. Base thicknesses along the south bound lane ranged from 310 to 600 mm. Base thicknesses along the north bound lane were less variable and ranged from 180 to 350 mm. Base thicknesses estimated after the pulverization process showed less variability than before the pulverization process. Pulverized asphalt concrete base thicknesses ranged from 260 to 400 mm on average.

Table 2 summarizes average DCP penetration rates for the pavement section. The data indicated that the pulverization process has generally produced a stronger base (lower penetration rate) compared to the base existing before the pulverization process. The data also show lower penetration rates for the subgrade; indicating an increase in subgrade strength with an improvement in the upper pavement structural condition. The results can be controversial since no rework was done in the subgrade to significantly increase the subgrade strength. It is believed that some friction between the DCP rod and the new base was taking place to reduce the penetration rate in the subgrade.

Falling Weight Deflectometer

The Dynatest Model 8082 Heavy Weight Deflectometer (HWD) test system was used to generate the required non-destructive load-deflection data. For this study, test loads ranged from 27 to 67 kN (6,000 to 15,000 lbf.). The sensor spacing was set at: 0, 200, 300, 800, 1200, 1600 and 2000 mm from the center of the load plate. Tests were performed every 50 meters along each lane. The FWD/HWD-generated load-deflection data were used to estimate pavement layer moduli using available mechanistic tools for pavement analysis. The software package used for analysis was the Dynatest ELMOD4.5.(6)

FWD Deflections

FWD deflections obtained at D0 (sensor at the load plate) and normalized for an impulse load of 40 kN are presented in Figure 1 for before and after the pulverization process. Table 3 summarizes average and standard deviation D0 deflections for the entire project. Included in Table 3 are asphalt concrete temperatures estimated from air temperatures (recorded with the FWD system) using Bell's equation.

The data indicate a decrease in D0 deflections after the pulverization process. The decrease was 49 and 42 percent for the South and North bound lanes, respectively. However, the reduction in deflections may not only be due to the new pavement structure but also to the low temperatures in the asphalt concrete at the time of testing. Average pavement temperatures at the time of testing before the pulverization process (June, 2001) were about 15 to 20°C higher than after the pulverization process (September, 2001). Testing in the portion of the project between stations 3200 and 4800 m that was not subjected to the pulverization process indicates that this temperature difference would decrease the deflections on the pavement by only about 30 percent.

Back Calculculated Modulus

The Dynatest program ELMOD 4.5 (6) was used to back-calculate modulus for a three-layer system consisting of: an asphalt concrete layer (AC), an unbound base layer (AB), and the subgrade (SG). Thicknesses for the asphalt concrete and base layers were obtained from extracted cores and DCP testing, respectively.

Back calculated moduli were obtained for the in-place asphalt concrete at the temperatures encountered during FWD testing and adjusted for an asphalt concrete temperature of 25°C. Figures 2 and 3 present estimated moduli for the asphalt concrete at 25°C before and after the pulverization process. Table 4 summarizes moduli of the layers before and after the pulverization process.

The data indicate higher base modulus with the pulverized asphalt concrete material than with the existing aggregate material before the pulverization process. Increased moduli may be due to improved compaction, and/or better base material produced by the pulverization process. The effect of a higher modulus base is better performance of a flexible pavement. In general, the high modulus base would reduce elastic deflections that produce fatigue cracking in the asphalt concrete and reduce stresses that cause permanent deformation (rutting) in the underlying unbound layers.

The DCP and FWD backcalculation process showed a consistent increase in the strength/modulus of the new base material; however, the subgrade strength/modulus variations estimated from the DCP and FWD were not consistent. The FWD showed no increase in the modulus of the subgrade while the DCP test indicated an increase in the subgrade strength. Reductions in the DCP penetration rate are believed to be influenced by the friction between the DCP rod and the new base material.

Pavement Life

The Dynatest program ELMOD 4.5 (6) was used to estimate the pavement life of the new structure for fatigue failure and rutting in the unbound materials. Fatigue failure was estimated by using the Asphalt Institute equation. Rutting in the unbound materials was evaluated based on the vertical stress on the top of the unbound layers. The analysis indicated that the new structure exceeded the pavement life provided by the overlays. Monitoring of the project will provide the true pavement life of the new structure.

Laboratory Testing Program

Laboratory testing was conducted to characterize the pulverized asphalt concrete material and two Caltrans aggregate base class 2 materials using standard and repeated loading tests. The laboratory results are compared to establish the relative response and performance of the pulverized asphalt concrete material to standard California bases.

Materials

The three materials used for laboratory testing were identified as follows:

1. AC Pulverization = the recycled asphalt concrete material used in the pulverization process in HWY 395 and sent to the Pavement Research Center (PRC) by Caltrans District 2. The material was obtained from behind the pulverizing equipment before it was compacted.
2. AB Cl 2 D2 = an aggregate base class 2 material sent to PRC by Caltrans District 2.
3. AB Cl 2 D4 = an aggregate base class 2 material used in Caltrans District 4 and in the accelerated pavement test sections at PRC.
4. AC Pulv. + 3% Lime = the pulverized AC mixed with 3 percent of lime. The lime was added at the optimum moisture content of the pulverized asphalt concrete material. The results presented in this paper are for 7 days of curing.

Standard Tests

Particle Size Distribution
Mechanical sieving was conducted following ASTM 136 (dry sieving) for the pulverized asphalt concrete material, and ASTM 117 (wet sieving) and 136 for the two aggregate base class 2 materials to determine the particle size distributions. ASTM 117 could not be performed on the pulverized material because the material bonds to itself during the oven drying process.
The results of the particle-size distributions are presented in Figure 4 for the pulverized asphalt concrete material, the two California aggregate base class 2 materials, and the Caltrans specification for a 19-mm aggregate base class 2 material. The data indicate that the pulverized material met Caltrans specifications.

Moisture-Density Relationship
Compaction tests were conducted following CTM 216. The results of the compaction tests are:

Base Material	Maximum Wet Density, kg/m^3	Optimum Moisture Content, %
Pulverized Asphalt Concrete	2460	5.5
AB Class 2 District 2	2380	6.5
AB Class 2 District 4	2210	6.5

Triaxial Tests

Static and repeated loading triaxial tests were conducted on prepared 152-mm diameter by 304-mm high cylindrical specimens. The specimens were tested on a closed-loop servo-hydraulic testing equipment capable of applying various sequences of stress levels. LVDTs and load cells were used to monitor load and displacement measurements. Measurements were recorded and processed using a high-speed data acquisition system (7). Static stress-strain triaxial tests and repeated loading tests (resilient modulus) were conducted on specimens compacted at optimum moisture content and at 95 and 100 percent maximum wet density according to CTM 216.

Stress-Deformation-Strength Characteristics
Displacement-controlled stress-strain triaxial tests were conducted on the specimens at confining pressures of 0, 35, 70, and 105 kPa. Stress-strain tests for the pulverized asphalt concrete mixed with 3 percent lime were only conducted at a confining pressure of 105 kPa. Typical stress-strain plots at a confining pressure of 105 kPa are presented in Figures 5 and 6 for specimens compacted at 95 and 100 percent maximum wet density according to CTM 216.
Stress-strain triaxial test results were used to define the shear strength of the materials using Mohr-Coulomb failure criteria. Mohr-Coulomb failure parameters for the two compaction levels considered are:

Base Material	95 % Maximum CTM 216		100 % Maximum CTM 216	
	Cohesion, kPa	Angle of Friction	Cohesion, kPa	Angle of Friction
Pulverized Asphalt Concrete	0.0	51.5	0.0	57.5
District 2 AB Class 2	0.0	51.0	0.0	56.5
District 4 AB Class 2	44.0	53.0	71.3	57.0

The data indicate that the pulverized material has similar static shear strength to the two California aggregate base Class 2 materials. The results also indicate the increase in shear strength of the materials when the compaction level is increased from 95 to 100 percent maximum wet density (CTM 216).

Resilient Modulus Tests

The resilient modulus tests were conducted following the Strategic Highway Research Program (SHRP) test protocol P-46 (8). Figure 7 and 8 presents the results of the resilient modulus tests for the materials investigated in terms of Resilient Modulus versus Sum of Principal Stresses ($\sigma_1 + 2\sigma_3$). The data indicate that the resilient response of the pulverized asphalt concrete material was significantly improved when mixed with lime. The pulverized material had the highest resilient modulus of the materials investigated. By comparing the untreated materials, the pulverized asphalt concrete had higher resilient modulus than the two aggregate base materials. Resilient modulus was also higher for the pulverized material (treated and untreated) and the aggregate base material (obtained in District 4) when the compaction level was increased to 100 percent CTM 216 maximum density. The increased compaction did not seem to have an effect on the resilient modulus of the aggregate base received from District 2.

The base modulus values obtained in the laboratory seem to conform to those obtained from the deflection analysis (see Table 3). Laboratory moduli for the pulverized material were between 300 and 450 MPa for 95 percent compaction and 450 and 650 MPa for bulk stresses ranging from 200 to 500 kPa. Field moduli for the pulverized material ranged on average from 310 to 580 MPa.

Permanent Deformation Resistance

Permanent deformation tests were not conducted because of insufficient pulverized material. However, researchers (9) have shown that aggregate materials tested under stress-strain triaxial tests that reached a deviatoric stress of at least 620 kPa at 2 percent strain under a confining pressure of 103.5 kPa had a low potential for rutting. Conversely, materials that did not reached a deviatoric stress of at least 620 kPa by 2 percent strain underwent a rapid accumulation of permanent deformation.

The stress-strain data shown in Figures 5 and 6 seem to indicate that the materials have a low potential for rutting. Deviatoric stresses for the base materials were between 650 and 800 kPa at 2 percent strain for a compaction level of 95 percent CTM 216 maximum density.

The data also indicate the reduction in the potential for rutting when the compaction level was increased from 95 percent to 100 percent CTM 216 maximum density. The materials reached deviatoric stresses between 1000 and 1200 kPa at 2 percent strain for a compaction level of 100 percent CTM 216 maximum density.

Summary of Field and Laboratory Test Results

The field tests (DCP and FWD testing) indicated that the new pulverized asphalt concrete base was stronger/stiffer than the existing base before the pulverization process. A stronger/stiffer base reduces the elastic deflections in the pavement that causes fatigue cracking in the asphalt concrete and reduces the potential for rutting in the unbound layers. Therefore, for the similar asphalt thicknesses of the overlay and pulverization strategies, the pulverization strategies would likely A continued field evaluation of the pulverized project would be required to support the initial success of the rehabilitation technique.

The laboratory data indicated that the pulverized material had higher resilient modulus and slightly higher shear resistance than the two California aggregate class 2 base materials. The laboratory program also indicates that the response and performance of the pulverized material can be significantly improved by increasing the compaction level in the field. Higher modulus and higher shear resistance were obtained at increased compaction levels. The limited laboratory study with lime indicated that the response and performance of the pulverized material seemed to improve by treating it with lime.

CONCLUSIONS

1. Based on the preliminary results of the pilot project, Caltrans engineers concluded that the pulverization strategy provides cost savings and an improved product. Cost savings were achieved in terms of time, material, and better performance. In terms of time, the overall speed of the process made it more competitive than the conventional rehabilitation strategy. In terms of material, the digout process was eliminated, which in turn eliminates the need to import material to the project location to fill the digouts. In terms of pavement performance, the potential for reflection cracking is eliminated, and the superior base obtained translates into lower deflections that could cause early fatigue cracking and lower stresses in the underlying unbound layers.
2. Based on the field testing, the results indicated that the pulverization process produced a better pavement than the pavement that was present before the pulverization process. Lower DCP penetration rates and higher moduli were obtained in the new rehabilitated pavement.
3. Estimates of pavement life indicated that the pulverization process produces a pavement structure that exceeds the pavement life provided by the overlay rehabilitation process. These initial estimates need to be verified through long-term monitoring.

4. Based on the laboratory testing, the results indicate that the pulverized material from Caltrans District 2 exhibited the better performance than the two aggregate base class 2 materials.. Higher shear strength and resilient modulus were obtained for the pulverized material than for the class 2 aggregate bases.
5. Laboratory results also indicated the benefits of increased compaction levels in the response and performance of unbound layers. Higher strength and resilient moduli were obtained at increased compaction levels that would reduce the fatigue cracking in asphalt concrete layers and rutting in unbound materials. The performance of the pulverized material from District 2 showed increase resilient response and performance when treated with lime.

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Table 1 Comparison of Initial Cost

Description	Unit	Quantity	Price	Amount
Strategy 1: Pulverization Process				**$3,634,800**
Pulverization Process	Station	160	1,950	312,000
Asphalt Concrete (150mm Type A)	Tonn	63900	52	3,322,800
Strategy 2: Asphalt Concrete Overlay with 20% Digouts				**$4,154,680**
Replace AC Surface	M3	2280	145	330,600
Asphalt Concrete (165 mm Type A)	Tonn	73540	52	3,824,080
Strategy 3: Asphalt Concrete Overlay with 40% Digouts				**$4,484,555**
Replace AC Surface	M3	4555	145	660,475
Asphalt Concrete (165 mm Type A)	Tonn	73540	52	3,824,080

Table 2 Summary of (DN) Penetration Rates

Unbound Layer	DN (mm/blow count)			
	Before Pulverization Process		After Pulverization Process	
	South Bound	North Bound	South Bound	North Bound
Base	5.1	6.6	3.2	3.6
Subgrade	13.7	11.9	6.3	9.0

Table 3 Summary of FWD D0 Deflections

Testing Stage	Lane							
	South Bound				North Bound			
	Mean µm	Standard Deviation µm	Coefficient of Variance %	Asphalt Concrete Temperature ºC	Mean µm	Standard Deviation µm	Coefficient of Variance %	Asphalt Concrete Temperature ºC
Before Pulverization	697.9	138.0	19.8	30.7	777.3	147.2	18.9	42.7
After Pulverization	355.9	56.1	15.8	15.6	451.8	80.6	17.8	20.7

Table 4 Summary of Estimated Modulus

Layer	Lane					
	South Bound			North Bound		
	Modulus, MPa	Standard. Deviation., MPa	Coefficient of Variance, %	Modulus, MPa	Standard. Deviation., MPa	Coefficient of Variance, %
	Before Pulverization Process					
Asphalt Concrete	1294.4	831.8	64.3	963.4	274.6	28.5
Aggregate Base	95.7	34.1	35.6	146.9	170.1	115.8
Subgrade	78.2	38.5	49.2	65.9	39.2	59.5
	After Pulverization Process					
Asphalt Concrete	1590.9	358.4	22.5	1302.1	216.5	16.6
Aggregate Base	579.1	290.1	50.1	310.5	160.8	51.8
Subgrade	65.5	23.0	35.1	62.6	29.5	47.1

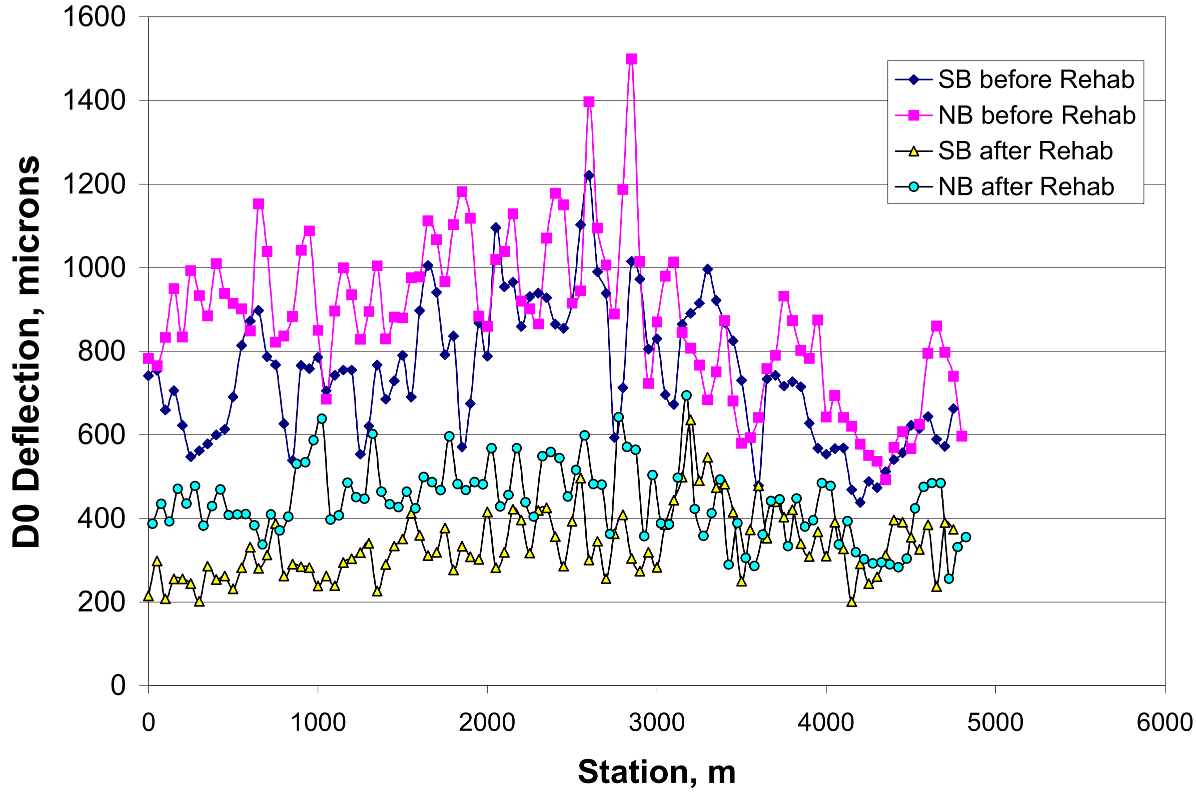

Figure 1 D0 Deflections Normalized at a 40 kN Load

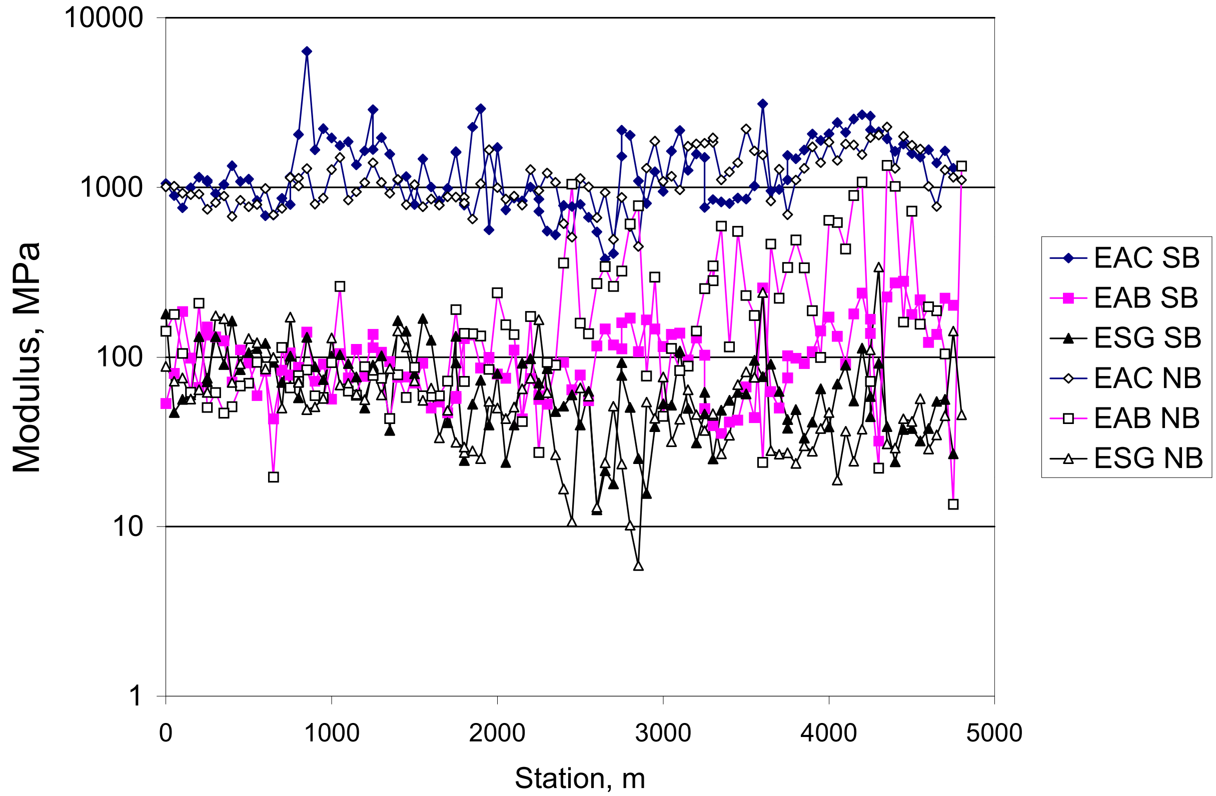

Figure 2 Estimated Modulus of Pavement Layers - Before Pulverization Process

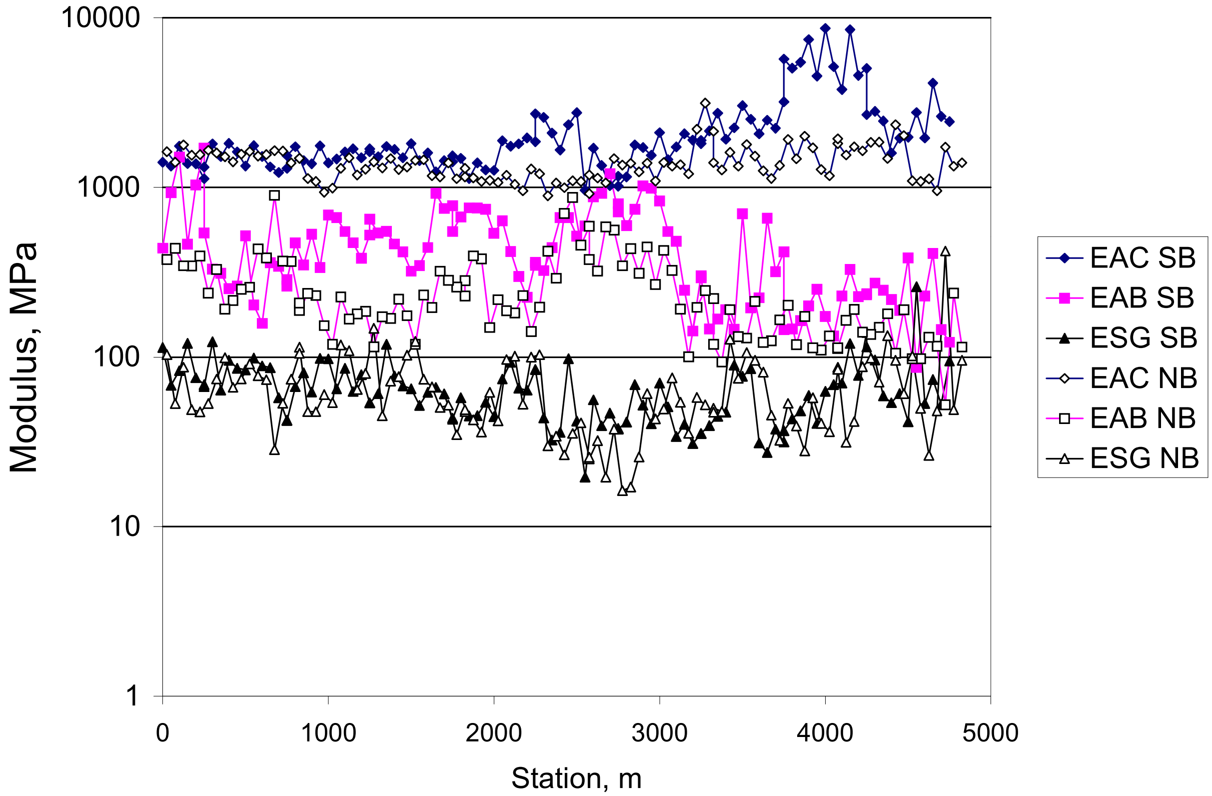

Figure 3 Estimated Modulus of Pavement Layers - After Pulverization Process

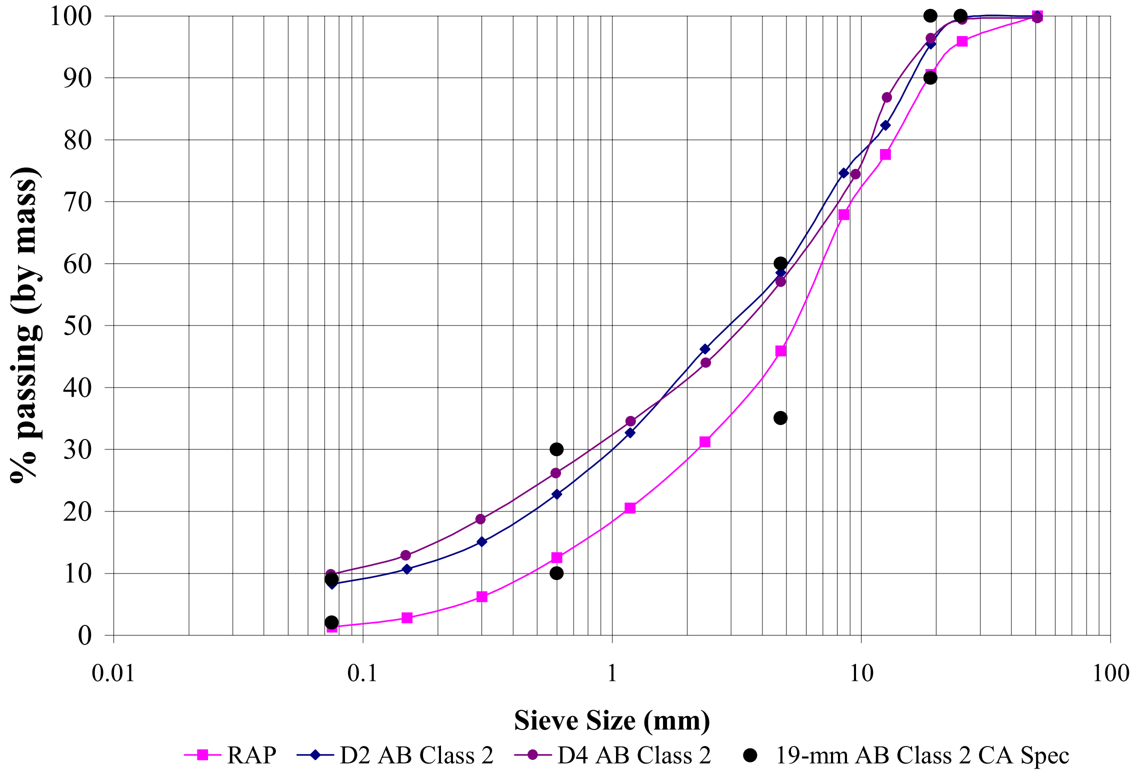

Figure 4 Grain Size Distribution of Base Materials

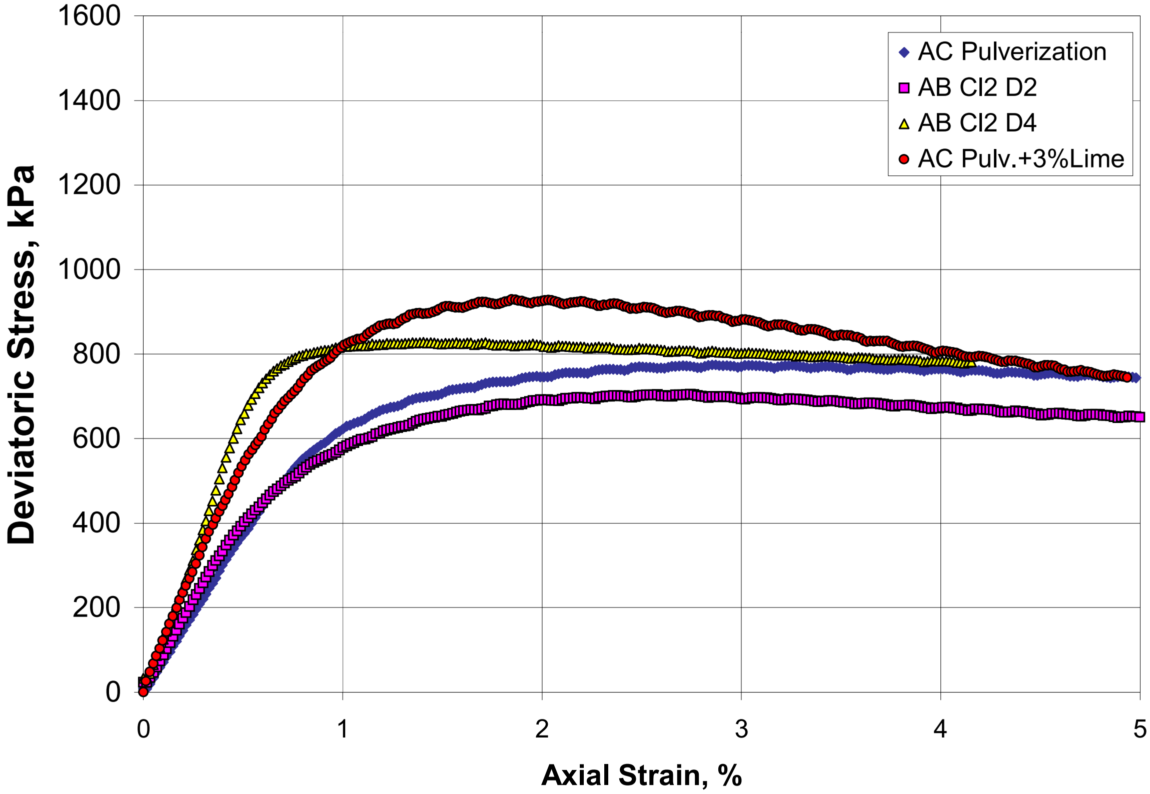

Figure 5 Drained Triaxial Test - 95% CTM 216 and 105kPa Confining Pressure

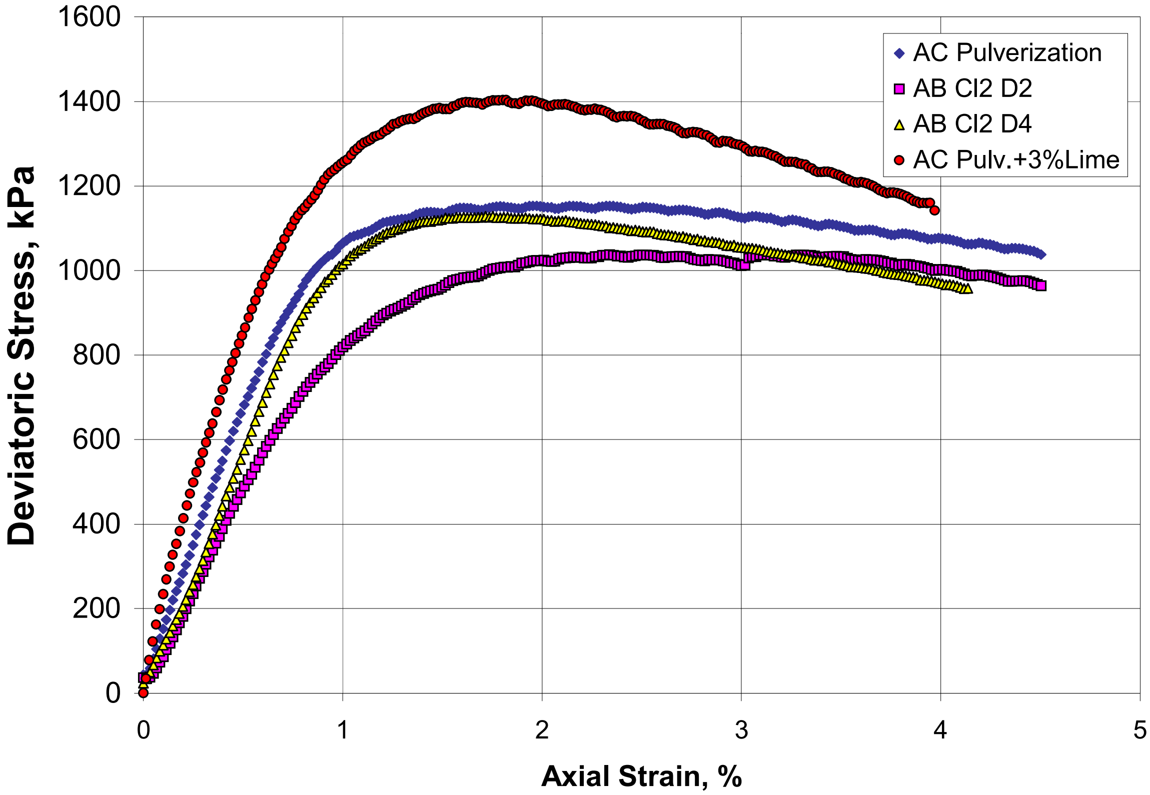

Figure 6 Drained Triaxial Tests - 100% CTM 216 and 105kPa Confining Presssure

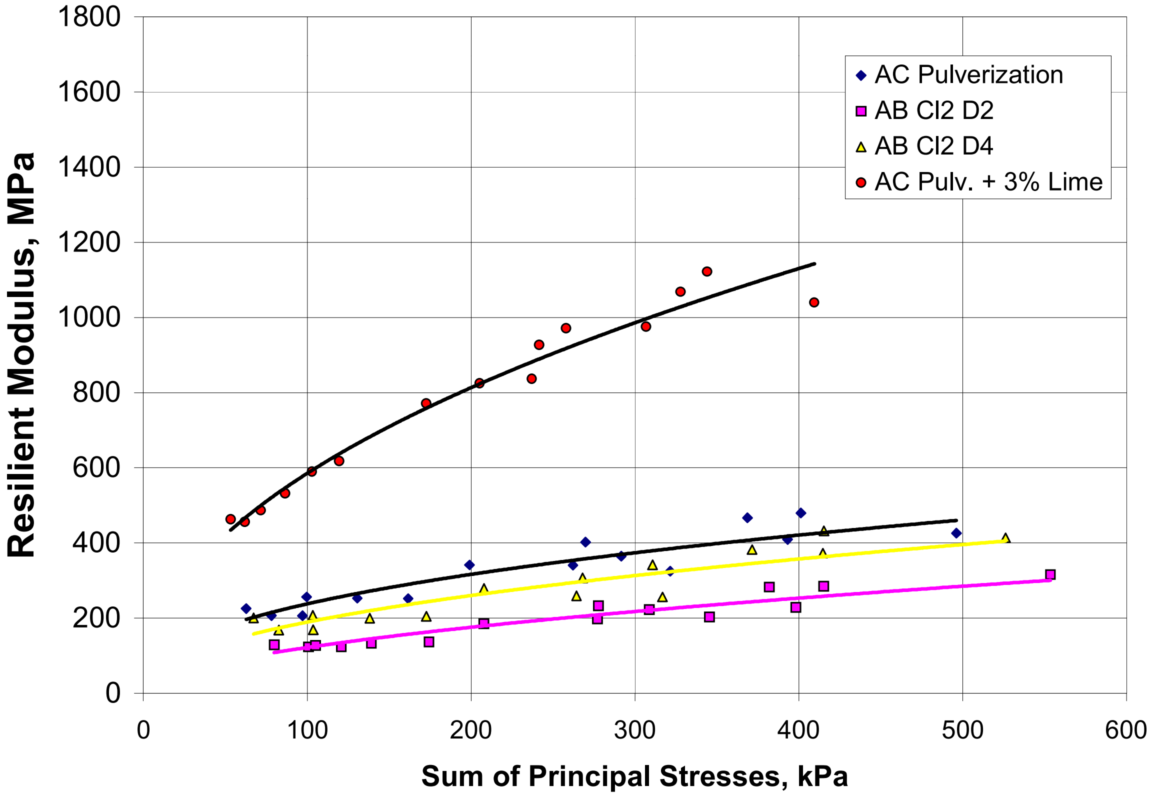

Figure 7 Resilient Modulus Characteristics of Base Materials - 95% CTM 216

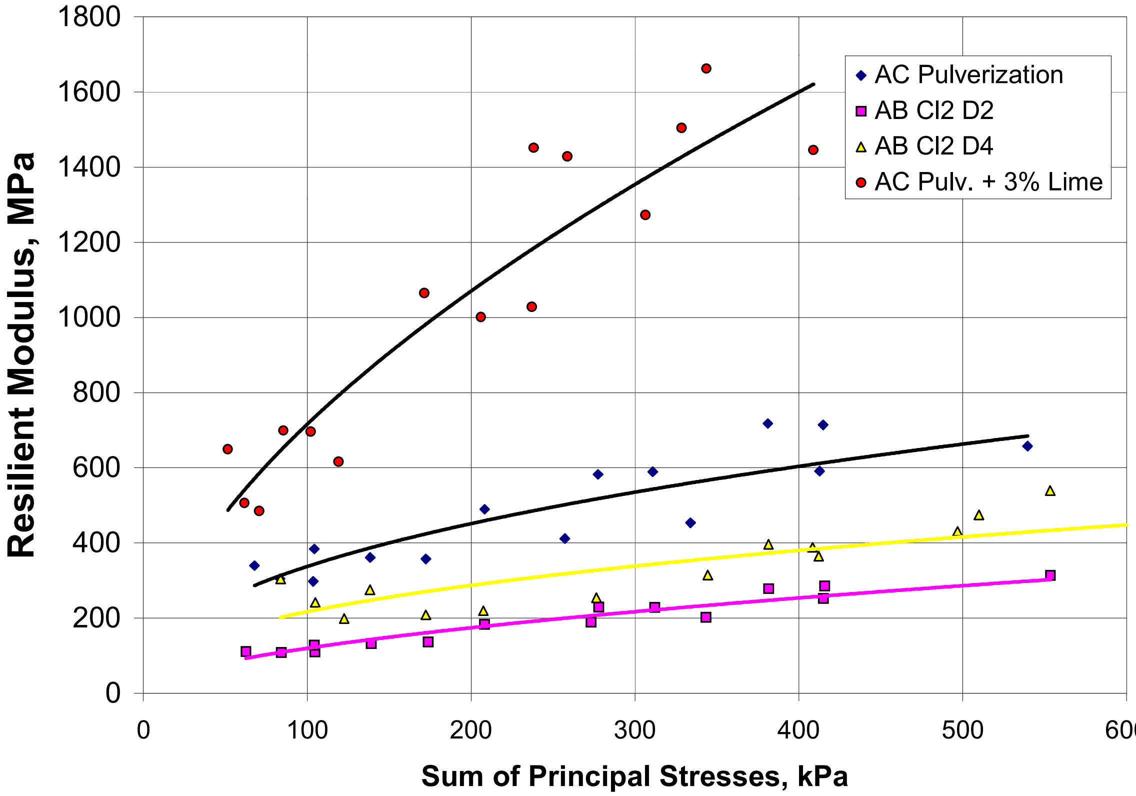

Figure 8 Resilient Modulus Characteristics of Base Materials - 100% CTM 216